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ULTRASONIC STUDIES OF ELASTIC PROPERTIES OF $LA_{1.84}SR_{0.16}CUO_4$ SUPERCONDUCTOR

IKRAM JAMEEL ABDUL GHANI

Department of Physics, College of Education of Pure Sciences, University of Baghdad, Baghdad, Iraq

ABSTRACT

Complete set of second order elastic constants and compliances besides Bulk modulus, shear modulus and Young modulus of $La_{1.84}Sr_{0.16}CuO_4$ superconductor single crystal have been measured using ultrasonic pulse superposition technique. By comparing the present values of SOEC with previous result of $La_{2-x}Sr_xCuO_4$, SOEC depend on the concentration of Sr in lanthanum- strontium- cupper- oxide compounds. C_{11} has been determined by the relation $C_{11}= \rho V_L^2$.

KEYWORDS: Elasticity, High-Temperature Superconductivity, Lanthanum Copper Oxide

INTRODUCTION

The first high temperature superconductor (high T_c or HTS) was discovered in 1986 by IBM researchers Karl Muller and Johannes Bednorz [1], for which they were awarded the Nobel Prize in physics in 1987. Their discovery of the first high T_c superconductor $LaBaCuO_4$, with transition temperature of 30K, generated great excitement.

In 1987 [2−4] found that substitution of strontium Sr for Ba in the La-Ba-CuO compound arises the transition temperature to approximately 40K. The superconducting $La_{2-x}Sr_xCuO_4$ is derived from the stiochiometric compound La_2CuO_4 by replacing La^{3+} with Sr^{2+} partially, and it has a tetragonal structure at room temperature. The high symmetry form which is tetragonal can be adopted by La_2CuO_4 at temperatures above 500K [5] and it is stabilized at lower temperatures by the partial substitution of Sr or Ba for La [6]. Among high –T_c cuprates, $La_{2-x}Sr_xCuO_4$ has the simplest crystal structure with single CuO_2 planes separated by the LaO charge reservoirs [7]. By substituting divalent strontium for trivalent lanthanum in La-based 214 compounds, the antiferromagnetism is destroyed [8]. $La_{2-x}Sr_xCuO_4$ compounds haves structure of perovskite type, belonging to the I4/ mmm space group [9] with unit cell structure represented in [10]. $La_{2-x}Sr_xCuO_4$ (LSCO) does not have a very high critical temperature, and in that respect is not a real high – temperature superconductor, however, the physics of LSCO classifies as that of a high temperature superconductor. It is very similar to that of other cuprates that all have a layered structure with copper oxide planes, and relatively simple lattice structure of LSCO compared with other cuprates, makes LSCO easier to study [10].

As more Sr was added into lanthanum copper oxide, more trivalent copper ions were obtained. Consequently, the stability of perovskite was further enhanced. The lattice parameters decreased with increasing strontium content and the volume of the perovskite subcell also decreased [11].

The aim of this work is to measure the second order elastic constants, elastic compliances, Bulk modulus and Young modulus of $La_{1.84}Sr_{0.16}CuO_4$ superconductor single crystal at room temperature using ultrasonic pulse superposition technique [12, 13].

In ceramic high-T_c superconductors, several attempts [14−27] have been made to determine the elastic constants as well as their elastic wave velocities experimentally. However, those attempts have led only to partial success due to the following limitations. Single crystals are usually in the form of platelets that do not allow the determination of the complete set of elastic constants. Also, because of the non-availability of perfect single crystals of fairly large size of ceramic superconductor, it was not possible to precisely measure the complete set of elastic constants.

Theoretical

It is usual practice in work on the centrosymmetrical, elastic stiffness (Cijkl) or compliance (Sijkl) constant tensors divide crystals into two Laue groups; 4/ mmm (TI) and 4/m (TII). The high-T_c superconducting crystal $La_{1.84}Sr_{0.16}CuO_4$ belongs to the tetragonal I4/mmm class [28] which has six independent elastic constants and compliances tensor components usually represented in matrix notation 11→ 1, 22→2, 33→3, 23 [32]→4, 13 [31]→5, 12 [21]→6 [29].

$$C_{ij} = \begin{matrix} C_{11} & C_{12} & C_{13} & 0 & 0 & 0 \\ C_{12} & C_{11} & C_{13} & 0 & 0 & 0 \\ C_{13} & C_{13} & C_{33} & 0 & 0 & 0 \\ 0 & 0 & 0 & C_{44} & 0 & 0 \\ 0 & 0 & 0 & 0 & C_{44} & 0 \\ 0 & 0 & 0 & 0 & 0 & C_{66} \end{matrix}$$

And

$$S_{ij} = \begin{matrix} S_{11} & S_{12} & S_{13} & 0 & 0 & 0 \\ S_{12} & S_{11} & S_{13} & 0 & 0 & 0 \\ S_{13} & S_{13} & S_{33} & 0 & 0 & 0 \\ 0 & 0 & 0 & S_{44} & 0 & 0 \\ 0 & 0 & 0 & 0 & S_{44} & 0 \\ 0 & 0 & 0 & 0 & 0 & S_{66} \end{matrix}$$

Stiffness and compliance are matrix reciprocals; the six independent components of each for 4/mmm are related by:

$$S_{11} = [C_{11}C_{33} – C_{13}]/ [(C_{11} – C_{12})\ C1]$$

$$S_{12} = – [C_{12}C_{33} – C_{13}]/ [(C_{11} – C_{12})\ C1]$$

$$S_{13} = – [C_{13}/ C1]$$

$$S_{33} = [(C_{11} + C_{12})/ C1$$

$$S_{44} = 1 /C_{44} \qquad S_{66} = 1 / C_{66}$$

$$C1 = [C_{33}\ (C_{11} + C_{12}) – 2\ C_{13}]$$

For TI Laue group (4/mmm), Bulk modulus; the ratio of normal stress to the volumetric strain with the elastic limit is given by [30].

$$B = 1 / 9 (C_{11} + C_{22} + C_{33}) + 2 / 9 (C_{11} + C_{13} + C_{23})$$

The Shear Modulus is given by

$$G = 1 / 15 (C_{11} + C_{22} + C_{33} – C_{12} – C_{13} – C_{23}) + 1 / 5 (C_{44} + C_{55} + C_{66})$$

Young modulus; the ratio of applied longitudinal stress to resultant longitudinal strain is given by:

$$E = (9BG) /(3B + G)$$

Experimental

Fairly large size of lanthanum- strontium- copper- oxide ($La_{1.84}Sr_{0.16}CuO_4$) single crystal has been used for measuring the complete set of elastic constants. Good quality ultrasonic longitudinal and shear wave signals were propagated along the direction of pressing of crystal of ceramic sample of $La_{1.84}Sr_{0.16}CuO_4$. It was detected by 5- MHZ X- or Y- cut (for longitudinal and shear waves, respectively) quartz transducers. A transducer correction was applied throughout to the measured transit time and hence, to the ultrasonic wave velocities.

RESULTS

The second order elastic constant C_{11} was determined using the equation $C_{11} = \rho V_L^2$, where V_L is the longitudinal wave velocity and ρ is the density of $La_{1.84}Sr_{0.16}CuO_4$ crystal (= 7113 kg / m^3) obtained by using the lattice parameters a = b = 0.377 nm and c = 1.322 nm [28]. The other elastic constants have been obtained using expressions comparing the coefficients of similar power of Lagrangian strain for lattice energy density and using Voigt's notation [27].

In table 1 some of the physical properties have been found for $La_{1.84}Sr_{0.16}CuO_4$ in present work at room temperature, compared with $La_{1.8}Sr_{0.2}CuO_4$ [19] which shows good agreement with slight differences. Table II shows the complete set of second order elastic constants and compliances of present work compared with previous work values of $La_{2-x}Sr_xCuO_4$ superconductor with different Sr concentrations [19, 21, and 31].

Table 1: Some of the Physical Properties Values of $La_{1.84}Sr_{0.16}cuo_4$ Compared with of $La_{1.8}Sr_{0.2}cuo_4$ Values [19]

Property	$La_{1.84}Sr_{0.16}cuo_4$	$La_{1.8}Sr_{0.2}cuo_4$
Density (kg/m^3)	7113	7122
Longitudinal V_L (m/s)	5674	5206
Shear V_S (m/s)	3625	3245
Bulk modulus B (GPa)	109.7	93
Shear modulus G (GPa)	65.97	—
Young's modulus E (GPa)	180.7	177

Table 2: Elastic Constants of $La_{1.84}Sr_{0.16}cuo_4$ (In 10^{11} N/ M^2) and Elastic Compliances (In 10^{-11} M^2/N) Compared with the Previous Work of $La_{2-X}sr_xcuo_4$ with Different Sr Concentrations [19, 21 And 31]

Stiffness Constants	$La_{1.84}Sr_{0.16}cuo_4$ [Present Work]	$La_{1.8}Sr_{0.2}cuo_4$ [19]	$La_{1.86}Sr_{0.14}cuo_4$ [21]	$La_{0.87}Sr_{0.13}cuo_4$ [31]
C_{11}	2.29	1.94	2.48	2.59
C_{12}	0.77	0.43	0.48	o.69
C_{13}	0.684	—	0.65	0.91
C_{33}	2.39	—	2.05	2.45
C_{44}	0.70	0.75	0.67	0.63

Table 2: Contd.,				
C_{66}	0.76	—	0.58	0.52
Compliances constants				
S_{11}	2.195	—	—	—
S_{12}	−15.188	—	—	—
S_{13}	−0.115	—	—	—
S_{33}	0.514	—	—	—
S_{44}	1.428	—	—	—
S_{66}	1.315	—	—	—

DISCUSSIONS

The elastic properties of $La_{1.86}Sr_{0.14}CuO_4$ superconductor are of interest for both technology and basic research. Anisotropy in elasticity is a fundamental property of the superconducting crystals. The experimental measurement on the elastic properties gives additional insight into the basic microscopic mechanism underlying the condensed state of this material. Below room temperature $La_{2-x}Sr_xCuO_4$ compounds show extreme acoustic mode softening [32, 33], the acoustic mode softening persists down to very low temperatures and is accompanied by a large ultrasonic attenuation [32, 34]. Suzuki et al [35] measured the longitudinal and transverse wave velocities over a wide temperature range from 1.8 to 300K in single crystal of $La_{1.86}Sr_{0.14}CuO_4$ and $La_{1.81}Sr_{0.19}CuO_4$. They also observed structural phase transition from tetragonal to orthorhombic phase at 210K with a large softening of C_{66} mode and a small softening of C_{11} mode.

Previous work on elastic properties of lanthanum-strontium- copper- oxide LSCO ceramic high – Tc superconductors has been reviewed by many workers [35 – 37]. Migliori et al. [21, 38] determined the elastic constants of $La_{1.86}Sr_{0.14}CuO_4$ single crystal using the method of eigen frequencies. Fanggao et al. [19] have measured three of six non –vanishing elastic constants of $La_{1.8}Sr_{0.2}CuO_4$ using ultrasonic technique. Bezuglyi et al. [31] have determined the elastic constants of $La_{1.87}Sr_{0.13}CuO_4$ from sound velocity measurements.

Table 1 shows good agreement between present measured experimental values of some physical properties of $La_{1.86}Sr_{0.14}CuO_4$ with previous results $La_{1.8}Sr_{0.2}CuO_4$ with slight differences. The values of second order elastic constants of present work are in good agreement with previous measured values of $L_{2-x}Sr_xCuO_4$ crystals with difference Sr concentrations as shown in table II.

Fairly large size crystal enabled us to measure the complete set of elastic constants successfully. Fanggoa et al. [19] used a crystal in the form of platelet which did not allow the determination of the complete set of elastic constants.

The values of second order constants of LSCO crystal depends on Sr concentration, the lattice parameters change and then the density of the crystal. Most of the ultrasonic investigations have been carried out on ceramic material $La_{1.84}Sr_{0.16}CuO_4$ with crystal defects such as voids, twins, microcracks and texture, which lower the sound velocity through the crystal and militate on the elastic properties values.

CONCLUSIONS

By applying ultrasonic pulse superposition technique, complete set of six second order elastic constants and elastic compliances have been measured for La1.84Sr0.16CuO4 single crystal and compared with previous results of SOECs for lanthanum- strontium- copper- oxide crystals with different concentrations of Sr. Good agreement has been found between the present work values of SOECs and some physical properties with previous results with slight

differences because of the concentration of Sr in the crystal and the size of the crystal.

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